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GB 0224689.0

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PO BOX 116,
Blackburn Highway Road,
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British Virgin Islands

Incorporated in the British Virgin Islands,

[ADP No. 08752552001]

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P01/7700 0.00-0224689.0

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3. Full name, address and postcode of the or of each applicant *(underline all surnames)*

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FIN-02150 ESPOO
FINLAND

SECTION 30 (1977 ACT) APPLICATION FILED 23/10/03

Patents ADP number *(if you know it)*

6572846002

If the applicant is a corporate body, give the country/state of its incorporation

FINLAND

4. Title of the invention

FORMATION OF CONTACTS ON SEMICONDUCTOR SUBSTRATES

5. Name of your agent *(if you have one)*

D Young & Co

"Address for service" in the United Kingdom to which all correspondence should be sent *(including the postcode)*

21 New Fetter Lane
London
EC4A 1DA

Patents ADP number *(if you know it)*

59006

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7. If this application is divided or otherwise derived from an earlier UK application, give the number and the filing date of the earlier application

Number of earlier application	Date of filing *(day / month / year)*

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Any other documents *(please specify)*	

11.

I/We request the grant of a patent on the basis of this application.

Signature D. Young & Co. Date 23 October 2002

D Young & Co (Agents for the Applicants)

12. Name and daytime telephone number of person to contact in the United Kingdom Dr Julian M Potter 020 7353 4343

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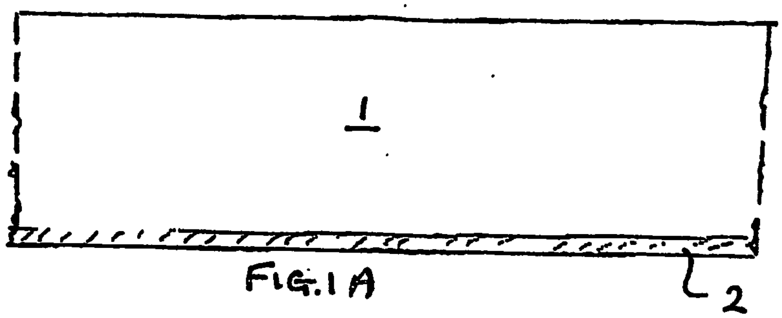

FIG. 1A

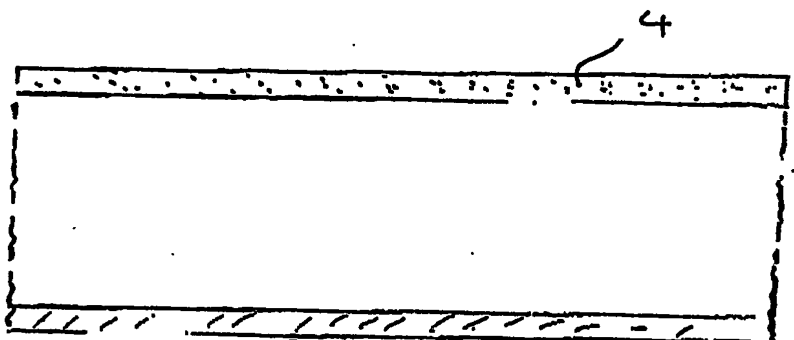

FIG. 1B

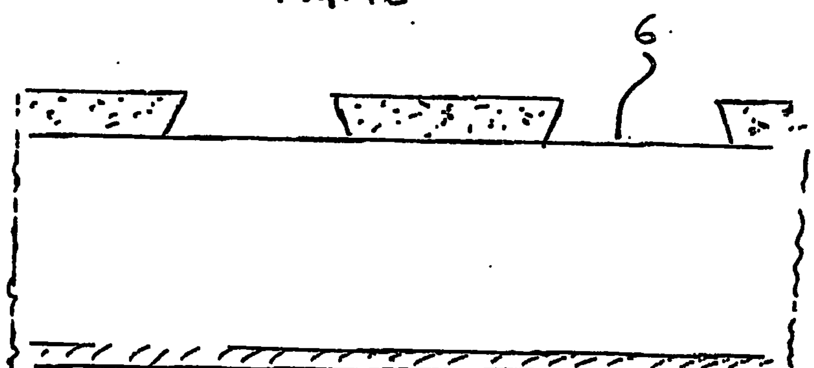

FIG. 1C

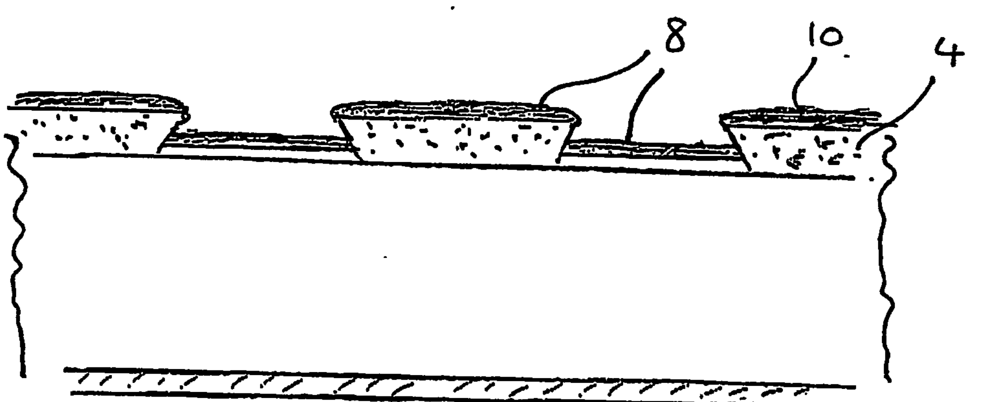

FIG. 1D

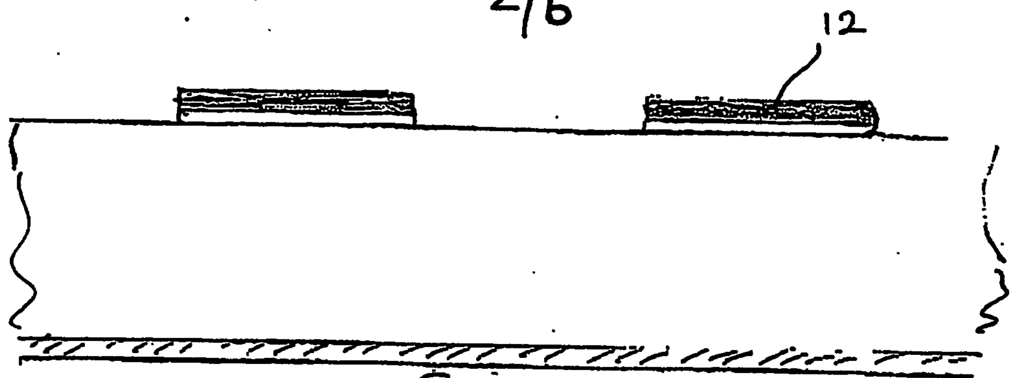

FIG.1E

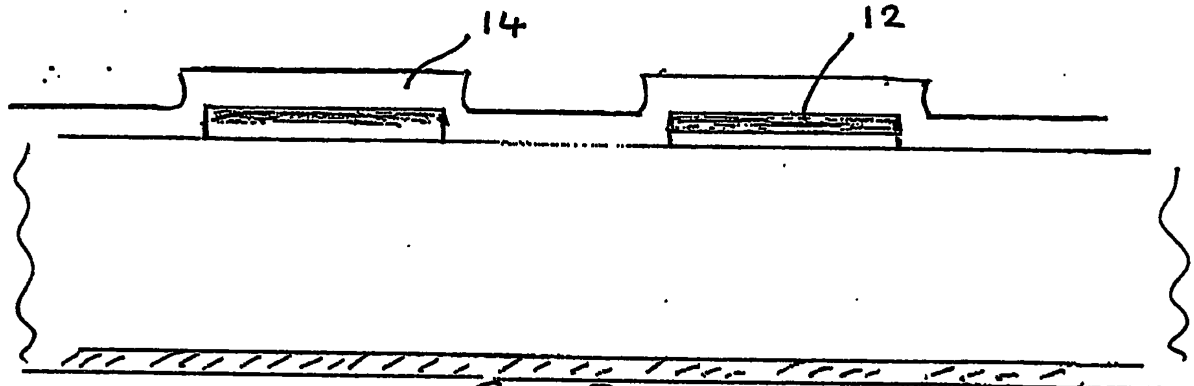

FIG.1F

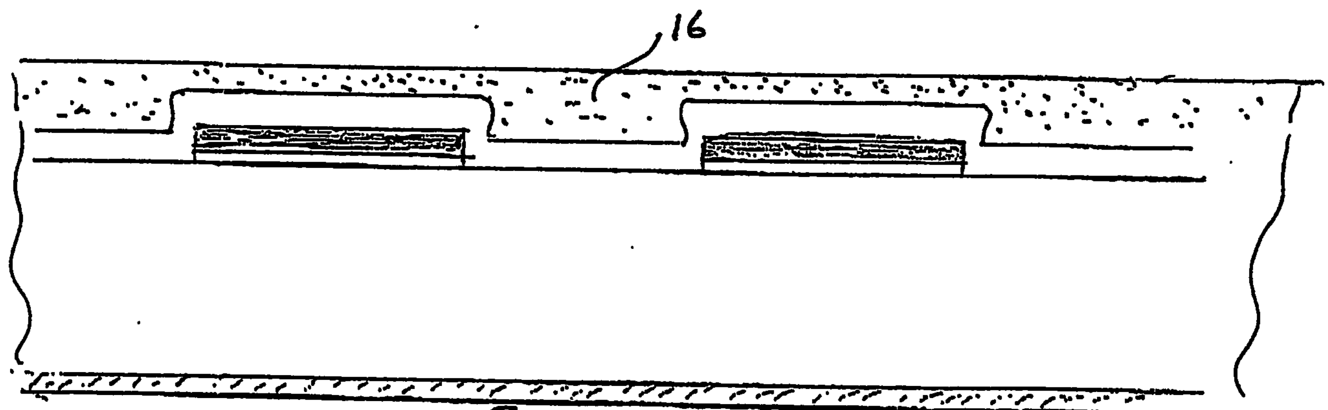

FIG.1G

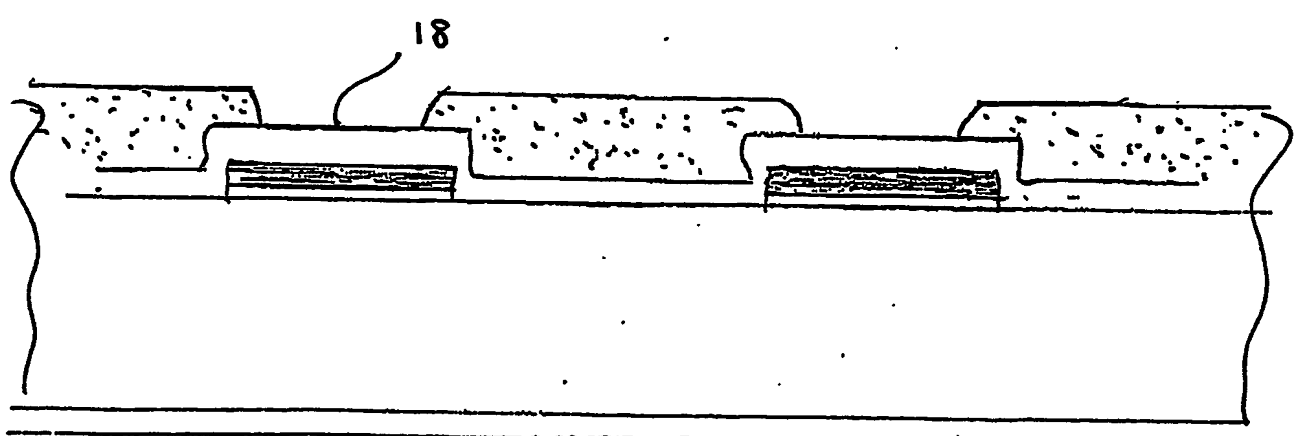

FIG. 1H

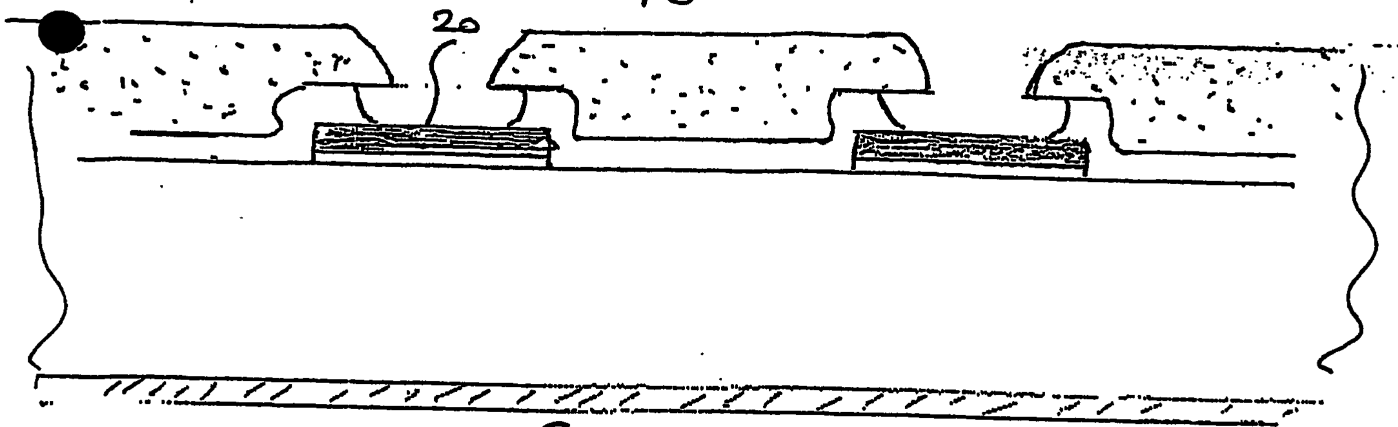

FIG. 1I

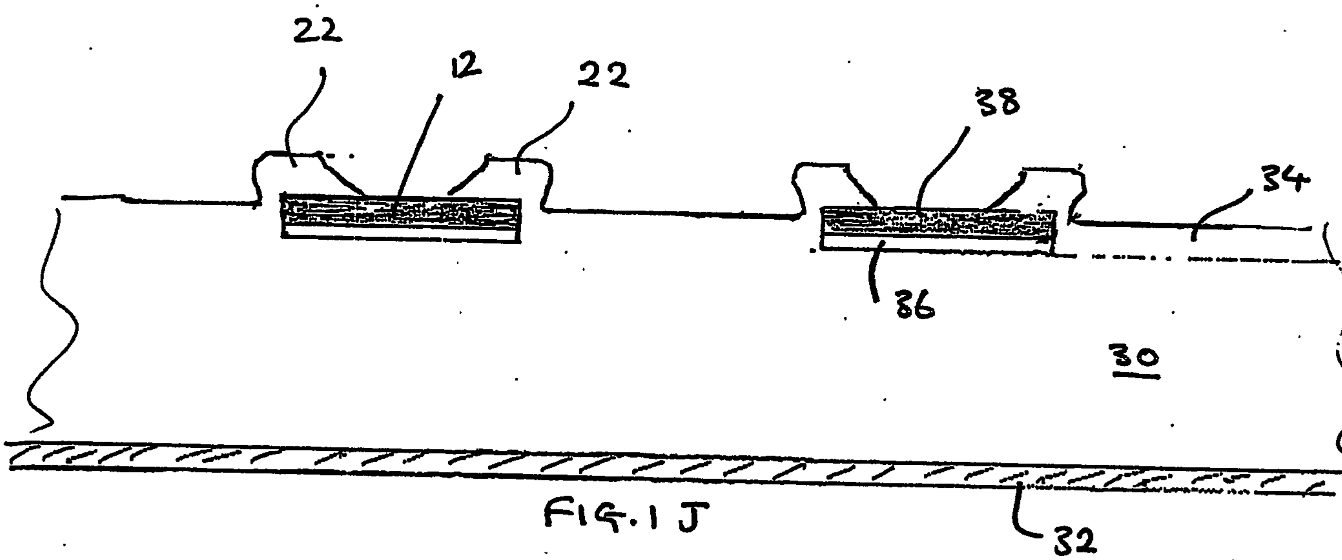

FIG. 1J

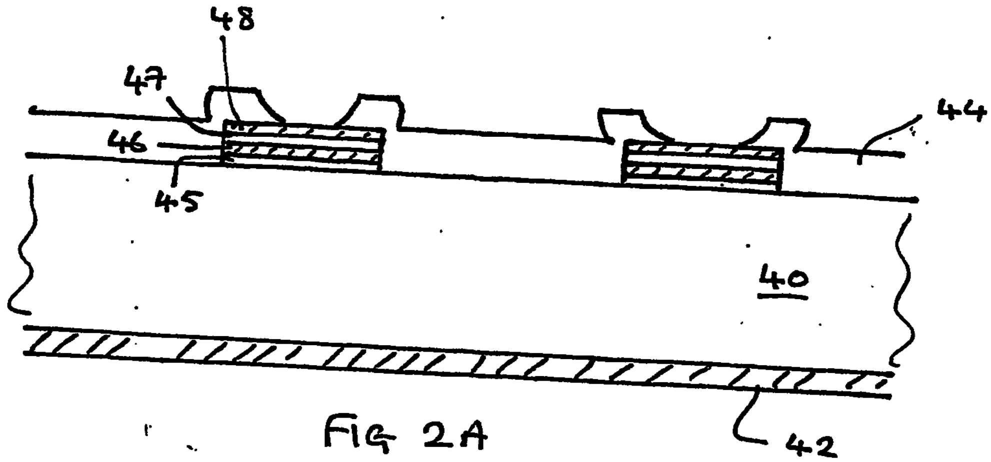

FIG 2A

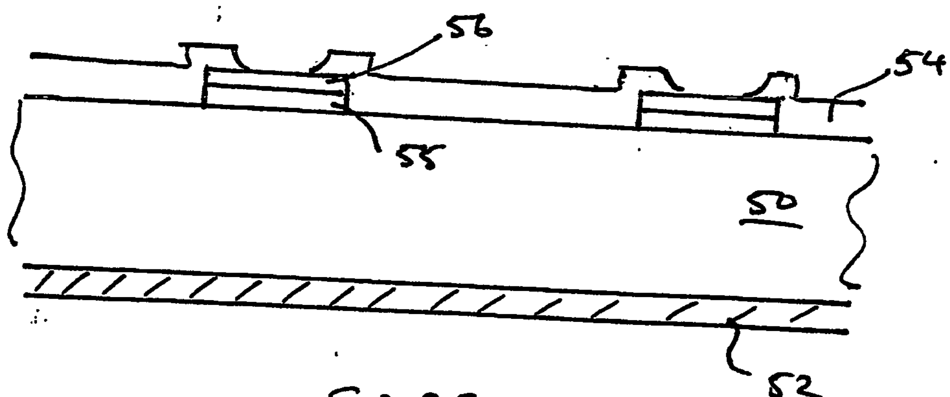

FIG. 2B

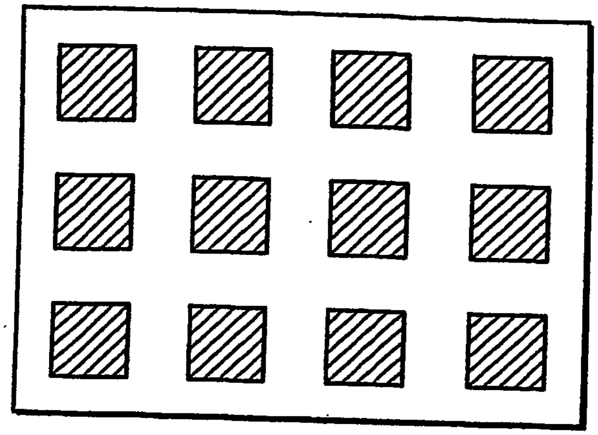

FIG. 3

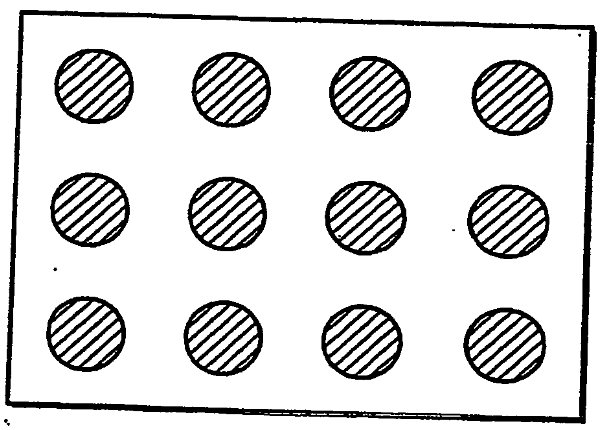

FIG. 4

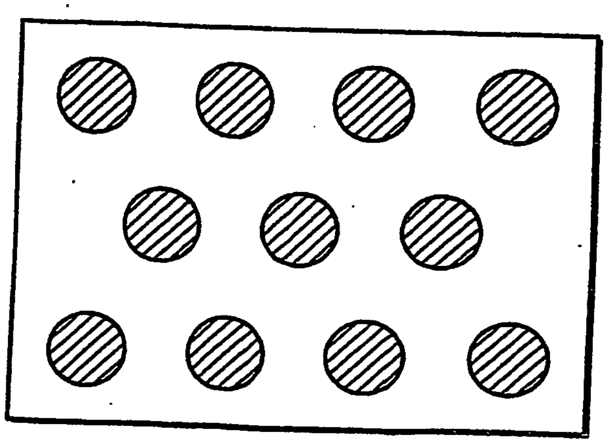

FIG. 5

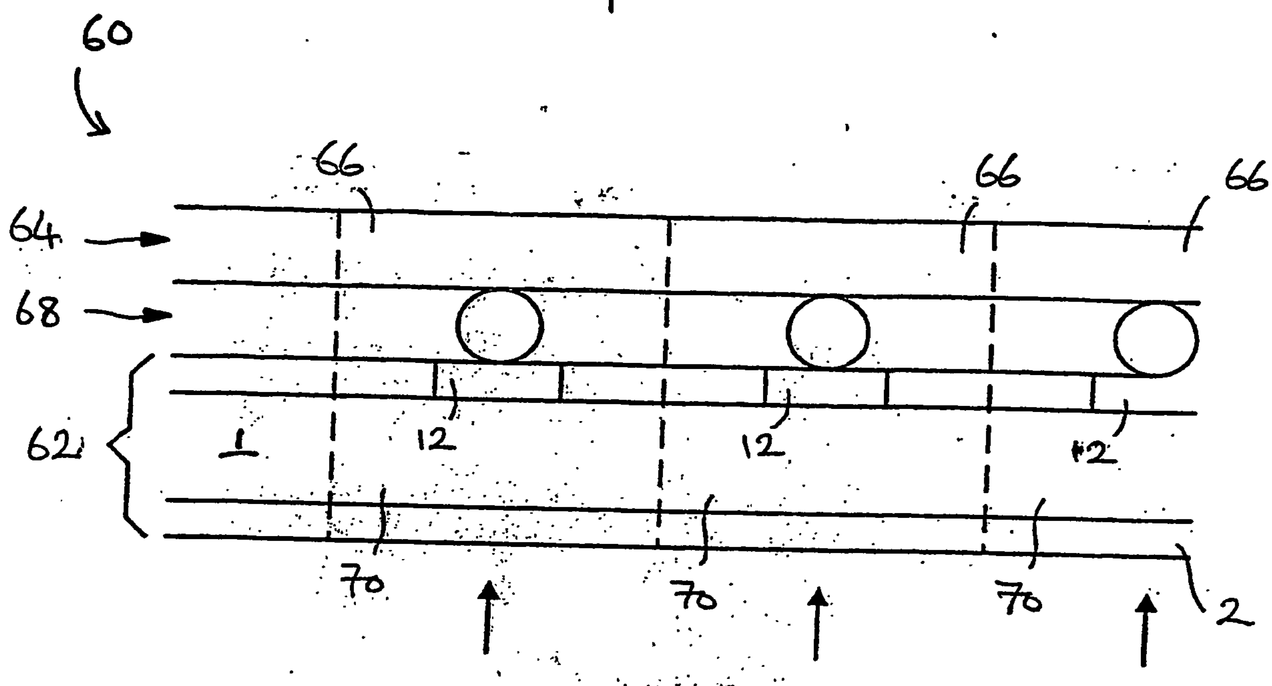

FIG. 6

DUPLICATE

FORMATION OF CONTACTS ON SEMICONDUCTOR SUBSTRATES

The invention relates to methods of manufacturing radiation detectors and radiation imaging devices, radiation detectors and imaging devices manufactured by these methods and the use of such imaging devices.

A radiation detector for an imaging device typically comprises a semiconductor substrate with a pattern or array of conductive contacts on one surface of the substrate defining an arrangement of detector cells.

Various semiconductor materials can be used in radiation detectors. For example, for optical wavelengths and charged radiation (beta-rays), silicon has typically been used for the semiconductor material for the substrate. Cadmium zinc telluride (CdZnTe), cadmium telluride (CdTe), titanium bromide (TiBr), mercury iodide (HgI) and gallium nitride (GaN) can be used in X-ray, gamma-ray and to a lesser extent beta-ray radiation imaging.

These detectors are produced commercially in a variety of sizes and thicknesses. Usually one or both sides of a planar detector are contacted with a continuous metal layer. Such detector substrates need to be processed to produce a detector having a pattern of contacts (e.g. pixel pads) on one surface, with the opposite surface remaining uniformly metallised, in order that the detector may be position sensitive, that is in order that the detector is able to produce a detector output indicating the position at which radiation impacts the detector. A readout chip then can be 'flip-chip' joined to the patterned side of the detector (e.g., by bump bonding using low temperature soldering with tin lead bismuth (PbSnBi) alloy solder or using balls of indium or conductive polymer material, gluing using conductive materials or other conductive adhesive layer techniques) so that the position dependent electrical signals which result from incidence and absorption in the detector cells of beta-rays, X-rays or gamma-rays for example, can be processed. The readout chip could be of the pulse counting type with very fast integration and processing time (typical a few

microseconds or at most a few milliseconds). Alternatively, it may be one of type described in the Applicant's International Patent Application PCT/EP 95/02056 which provides for charge accumulation for individual detector cells.

The Applicant's UK patent application GB 2,352,084A describes a method of manufacturing a radiation detector having conductive contacts on a semiconductor substrate at positions for defining radiation cells. The method includes the steps of forming a layer of passivation material on a surface of the substrate; removing areas of the layer of passivation material to form openings to the substrate surface at the contact positions; forming a layer of conductive material (e.g. metal) over the layer of material and the openings; and removing conductive material over the layer of material to separate individual contacts.

The benefits of the method of GB 2,352,084A are set out in that application. However, certain problems with this and other known methods have been identified. These include that the methods are fairly complex, the embodiments comprising a fairly large number of steps. Furthermore, hot spots and poor or uneven electrical characteristics have been observed in radiation detectors produced by these methods. This is disadvantageous because the quality of the electrical characteristics of the radiation detector is extremely important for imaging performance. It is therefore desirable to provide a less complex method and one which results in radiation detectors with improved electrical properties.

The present invention is made with the above considerations in mind.

In accordance with one aspect of the invention, there is provided a method of manufacturing a radiation detector having one or more conductive contacts on a semiconductor substrate at positions for defining one or more radiation detector cells, said method comprising the steps of:

(a) forming said conductive contacts on a surface of said semiconductor substrate to leave regions open to the surface of said semiconductor substrate around said conductive contacts;

(b) forming a layer of material on said conductive contacts and the regions around conductive contacts; and

(c) removing portions of said layer of material overlying said conductive contacts to expose the conductive contacts.

Forming the conductive material before forming the layer of material, that is by performing step (a) before step (b), is a complete departure from known approaches. By doing this, embodiments in accordance with the invention can be performed in fewer steps.

Furthermore, the inventors have observed that using a method which involves forming a layer of material (such as passivation material) on the surface of the substrate and then removing areas of the material to form openings to the substrate, such as one in accordance with GB 2,352,084 A, can lead to radiation detectors with poorer than expected electrical characteristics.

It is thought that forming the material (e.g. passivation material) on the semiconductor surface contaminates the semiconductor material near its surface by the introduction of impurities (e.g. passivation material and/or etchant) and that this alters the electrical properties of the semiconductor and hence the detector. Impurities remaining on the semiconductor surface may also contribute to altering electrical properties of the detector by contaminating the conductive layer and by causing less than fully controlled electrical contact between the conductive contacts and the semiconductor surface.

In contrast to known methods, the introduction of impurities is avoided by forming the layer of conductive material first. In embodiments constructed in accordance with the invention, this can improve electrical contact characteristics, reduce hotspots, improve yield and improve detector quality. Homogenous contacts with even electrical contacts can thus be reliably produced.

Typically, an array comprising a plurality of conductive contacts is formed on the surface of the semiconductor substrate (in step (a)) and the layer of material is formed on the conductive contacts and on the regions in between the contacts. However, radiation detectors having a single conductive contact can be manufactured in accordance with embodiments of the present invention.

The layer of material may be any suitable material and is preferably a material which is insulative.

In a preferred embodiment, the layer of material comprises a layer of passivation material which may be insulative and may also protect against environmental or chemical damage. The use of such an insulating layer means that after manufacture of the detector, the passivation material remains between the contacts protecting the semiconductor surface from environmental damage in use and further enhancing the electrical separation of the contacts.

Optionally, step (a) comprises:

a(i) forming a layer of photoresistive material on said substrate surface;

a(ii) selectively exposing said photoresistive material and removing said photoresistive material from areas corresponding to said contact positions to expose said semiconductor substrate surface;

a(iii) forming a layer of conductive material on remaining photoresistive material and on said exposed semiconductor substrate surface; and

a(iv) removing conductive material overlying said remaining photoresistive material by removing said remaining photoresistive material (lift-off).

Optionally, step (c) comprises:

c(i) forming a further layer of photoresistive material over said layer of material;

c(ii) selectively exposing said further layer of photoresistive material and removing said further photoresistive material to expose portions of said layer of material corresponding to said contact positions;

c(iii) removing said exposed portions of material; and

c(iv) removing remaining further photoresistive material.

The surface resistivity of cadmium-based substrates in particular, for example a CdZnTe semiconductor substrate, is degraded when the substrate is exposed to metal etchants suitable for removing gold and/or platinum, for example. As a result of this, the electrical separation of the individual contacts which result from some known methods of forming such contacts is not as good as would be expected from the properties of that material before treatment. By using a lift-off method in accordance with the invention, metal etchants need not be used, thus avoiding the damage which would result if the metal etchants came into contact with the semiconductor surface.

In a preferred embodiment, portions of the layer of material (e.g. passivation material) are removed from areas corresponding generally to the contact positions. However, by applying a further layer of photoresistive material the exposure of areas smaller or larger than the contact positions is possible. Preferably, portions of the layer of material are removed from areas smaller than the conductive contacts. After removal of the portions of said layer of material, the material can overlap the conductive contacts. This means that the passivation material may be applied over portions of the conductive contacts. This provides good mechanical contact, and reduces the possibility of gaps being formed between the conductive material and passivation material.

Embodiments in accordance with the present invention may be used to define areas or regions away from, yet operatively related to, contact positions. This is particularly advantageous and is intended for use in manufacturing high energy (1KeV) radiation imaging devices since it allows more complex conductive material patterns to be formed. For example, for off-setting a charge collection contact of a detector cell relative to a corresponding contact of a read-out substrate cell.

Optionally, the further photoresistive material is removed from areas of passivation material to expose said areas in a desired pattern for forming conductive tracks.

To protect the other main surface and the sides (edges) of the semiconductor substrate, photoresistive material can additionally be applied to all exposed surfaces as well as the surface on which the conductive contacts are formed.

Aspects of the invention find particular, but not exclusive, use with cadmium-based substrates such as those formed of cadmium zinc telluride (CdZnTe) or cadmium telluride (CdTe). It will be appreciated that the method of the invention can be used with other substrate materials as well, for example lead iodide, thallium bromide, gallium arsenide, titanium bromide, mercury iodide, gallium nitride, or silicon.

Typically the conductive layer is a metal, a metal alloy, or a stack of metals and/or metal alloys.

Preferably, the conductive material layer for forming said contacts is applied by a method such as sputtering, evaporation, electrolytic deposition, or electroless deposition (e.g. chemical deposition), preferably by sputtering.

Suitably, the metal for forming the conductive contacts can comprise gold (Au), platinum (Pt), indium (In), titanium (Ti), tungsten (W), or nickel (Ni) although other metals could be used. These can be used as a single layer on their own, or as components of a stack of metals. Preferably, the metal alloy is a nickel/gold alloy or a titanium/tungsten alloy. As a stack, metals can be used with other metals, metals can be used in combination with alloys or alloys can be used in combination with other alloys.

Preferably, the passivation layer is formed of Aluminium nitride(AlN). Aluminium nitride is particularly beneficial because it increases residual resistance between conductive contacts.

Each conductive contact can define a respective pixel cell of an array of pixel cells, or one of a plurality of strips arranged parallel to each other.

With a method according to the invention, the conductive contacts can be from about 5μm to about 100μm across with a pitch from about 7μm to about 500μm. Preferably, the conductive contacts are of the order of 15μm across with a pitch of the order of 35μm.

Another aspect of the invention provides a method of manufacturing a radiation detector, comprising a semiconductor substrate with one or more conductive contacts for respective radiation detector cells on a first surface thereof and a layer of conductive material on a surface of the substrate opposite to said first surface, the conductive contacts being formed on the first surface by a method as described above. The layer of conductive material can be formed on the opposite surface of the substrate prior to step (a) of the method described above.

Suitably, the conductive material can be a metal or metal alloy.

An aspect of the invention further provides a method of manufacturing a radiation imaging device comprising manufacturing a radiation detector as defined above; and individually connecting individual detector cell contacts for respective detector cells to corresponding circuitry on a readout chip. Suitably, the individual contacts may be connected by a flip-chip technique.

In accordance with another aspect of the invention, there is provided a radiation detector comprising a semiconductor substrate for detecting radiation with a plurality of conductive contacts for respective radiation detector cells on a first surface thereof and a layer of conductive material on a surface of said substrate opposite to said first

surface, wherein the exposed width of a said conductive contact is smaller that the overall width of said contact adjacent said substrate.

The semiconductor substrate may be any suitable semiconductor material for imaging radiation, for example cadmium zinc telluride (CdZnTe), cadmium telluride (CdTe), lead iodide, thallium bromide, gallium arsenide, titanium bromide, mercury iodide, gallium nitride, or silicon.

In a preferred embodiment of the invention the semiconductor substrate is cadmium-based such as cadmium zinc telluride (CdZnTe) or cadmium telluride (CdTe), preferably cadmium zinc telluride (CdZnTe). Preferably, passivation material is provided between individual contacts. Aluminium nitride has been found to be particularly effective as a passivation material for CdZnTe because it can be applied at low temperature, CdZnTe being temperature sensitive. Using aluminium nitride at low temperature is beneficial because there is little expansion during the application and consequently the introduction of excessive stress into the structure due to expansion is avoided.

The metal contacts can define an array of pixel cells, or a plurality of strips arranged parallel to each other, depending on the field of use of the detector.

Pixel contacts formed on detector substrate are preferably substantially circular and are arranged in a plurality of rows, more preferably with alternate rows preferably being offset from adjacent rows.

The conductive contacts can be from about $5\mu m$ to about $100\ \mu m$ across with a pitch from about $7\mu m$ to about $500\ \mu m$. In a preferred embodiment the conductive contacts are of the order of $15\ \mu m$ across with a pitch of the order of $35\ \mu m$.

In detectors in accordance with the invention, the resistivity between metal contacts should be in excess of $1G\Omega$/square, preferably in excess of $10G\Omega$/square,

more preferably in excess of 100GΩ/square and even more preferably in excess of 1000GΩ/square (1TΩ/square).

The invention also provides a radiation imaging device comprising a radiation detector as defined above and a readout chip for receiving charge from the conductive contacts of the radiation detector. Suitably, the individual contacts may be connected by a flip-chip technique.

A radiation imaging device in accordance with the invention finds particular, but not exclusive, application for X-ray, gamma-ray and beta-ray imaging.

Thus, one particular embodiment of the invention can provide a method for manufacturing detectors (e.g. a cadmium based substrate such as CdTe or CdZnTe) with one side uniformly metallised with a metal such as indium or platinum and the other side patterned with conductive contacts structures (e.g. a platinum/ gold/ nickel/ gold stack) in a manner that does not adversely affect the surface characteristics of the substrate around or in between the contacts. Thus, a method can be provided for creating conductive structures on one side of a detector, the method achieving inter-structure resistivity of the order of GΩ/square or tens or hundreds of GΩ/square. The conductive contact structures may be patterned to provide readout tracks, for example.

The use of an electrically insulating passivation layer between contacts further enables the area between metal contacts to be protected, thus giving the detector stable performance over time and avoiding effects such as oxidation which increase the surface leakage current and decrease the inter-contact resistivity. Aluminium nitride (AlN) passivation has been found to be particularly effective when applied between gold contacts to protect the surface and enhance the electrical separation of the gold contacts. The passivation layer of aluminium nitride can be implemented at relatively low temperatures typically less than 100°C. By contrast, silicon oxide (SiO_2), which is typically used as a passivant for silicon (Si) semiconductors, needs temperatures in excess of 200°C. After exposure to these temperatures, CdZnTe would be unusable.

In some known radiation detectors, problems have been observed with certain characteristics of the conductive contacts. These include the conductive contacts having poor adhesion properties and shorter than desired life times. Shorter than desirable life times have been observed when radiation detectors are joined to a readout chip in a radiation imaging device, via a bump bonding technique using PbSnBi solder, for example.

In another aspect of the present invention provides a method of manufacturing a radiation detector having one or more conductive contacts on a semiconductor substrate at positions for defining one or more radiation detector cells, the method including the steps of:

forming said conductive contacts on a surface of said semiconductor substrate in the form of a stack of different conductive materials wherein the stack comprises:

a contact layer on the substrate surface;

an adhesion layer;

a diffusion barrier layer; and

a wetting agent layer.

Advantageously, embodiments in accordance with this aspect can provide particularly good chemical contact with the substrate (via the contact layer), particularly good adhesion (via the adhesion layer); improved lifetime (via the diffusion barrier layer) and good bonding to the readout chip by the wetting agent layer acting as a wetting agent for the bump bonding. Advantageously, the diffusion barrier layer prevents bump bond material (e.g. PbSnBi solder) from diffusing into lower layers which is detrimental to the lifetime of the detector.

Preferably, the substrate is cadmium-based such as CdTe or CdZnTe.

Preferably, the contact layer comprises platinum, the adhesion layer comprises gold, the diffusion barrier layer comprises nickel and the wetting agent layer comprises gold.

In another aspect of the present invention provides a method of manufacturing a radiation detector having one or more conductive contacts on a semiconductor substrate at positions for defining one or more radiation detector cells, the method including the steps of:

forming said conductive contacts on a surface of said semiconductor substrate in the form of a stack of different conductive materials wherein the stack includes:

a contact layer comprising platinum on the substrate surface.

Advantageously, platinum gives a particularly good chemical contact with the semiconductor substrate.

In another aspect the present invention provides a method of manufacturing a radiation detector having one or more conductive contacts on a semiconductor substrate at positions for defining one or more radiation detector cells, the method including the steps of:

forming said conductive contacts on a surface of said semiconductor substrate in the form of a stack of different conductive materials wherein the stack includes;

a diffusion barrier layer to prevent diffusion of joining material for joining the contacts to a readout chip from diffusing into a layer beyond the diffusion barrier layer.

Advantageously, lifetime of the detector is improved.

Preferably the diffusion barrier layer comprises nickel.

It will be appreciated that stacks of conductive material can be used in several embodiments of the present invention. Example stacks include platinum/ gold/ nickel/ gold; platinum/ gold/ nickel; platinum/ gold/ indium/ gold; platinum/ gold; indium/ gold; chrome/ copper/ gold; and platinum/ titanium-tungsten alloy/ gold.

Embodiments of the invention will be described hereinafter, by way of example only, with reference to the accompanying drawings in which:

Figure 1 is an example of a method of forming metal contacts on a semiconductor substrate with a passivation layer between contacts;

Figure 2 illustrates some examples of detector substrates;

Figure 3 is a schematic plan view of one contact configuration on a detector substrate;

Figure 4 is a schematic plan view of another contact configuration on a detector substrate;

Figure 5 is a schematic plan view of a further contact configuration on a detector substrate; and

Figure 6 is a schematic cross-section of a radiation imaging device.

Figure 1 illustrates an example of a method in accordance with the invention of forming conductive contacts on a semiconductor substrate at positions for defining radiation detector cells with a layer of passivation material between the detector cells. The semiconductor substrate may be made of any suitable semiconductor material including, but not limited to, cadmium zinc telluride (CdZnTe), cadmium telluride (CdTe), lead iodide, thallium bromide, gallium arsenide or silicon. The material used for the conductive layer and the contacts may be any suitable conductive material, including, but not limited to metals, for example, nickel, gold, platinum, titanium, tungsten or indium, or metal alloys, for example a nickel/gold alloy or a titanium/tungsten alloy and may be a sequence or stack of layers of two or more different metals. In addition, any suitable passivation material may be used, including, but not limited to, aluminium nitride.

Thus, Figure 1 is a schematic cross-sectional view from the side of a detector substrate at various stages in the formation of conductive contacts on a semiconductor substrate.

Step A: The detector substrate 1 has one face (the lower face in Figure 1) uniformly metallised with conductive material 2.

Step B: Photoresistive material (photoresist) 4 is spun on the bare face (the upper face in Figure 1) of the detector 1 and preferably on the sides of the detector.

Step C: Openings 6 exposing the substrate surface are made in the photoresist 4 using an appropriate mask or other conventional technique for removing photoresist according to a desired pattern. The remaining photoresist is a negative profile of the positions for forming the conductive contacts and/or tracks (for a lift off process).

Step D: Conductive material 8 is sputtered, evaporated or laid by electrolysis or electroless deposition (e.g. chemical deposition) uniformly over the exposed substrate surface (through openings 6) and the photoresist 4, as a result of which the conductive material covers the photoresist 4 and the exposed substrate surface.

Step E: The remaining photoresist of photoresist layer 4 is removed, suitably by dissolving with a solvent such as acetone, thereby lifting off unwanted conductive material areas 10 to expose areas of the substrate surface between conductive contacts 12.

Step F: Passivation material 14 is sputtered over the exposed areas of the substrate surface and over the conductive contacts 12.

Step G: A further layer of photoresist 16 is spun on the passivation layer 14.

Step H: Photoresist layer 16 is removed in portions to expose portions 18 of the passivation layer overlying the conductive contacts. The removed portions of the photoresist layer 16 and consequently the exposed portions 18 are slightly smaller in area than the area of the conductive contacts 12.

Step I: Openings 20 are made through the exposed portions of the passivation layer with a passivation etchant (e.g. an aluminium nitride etchant) to expose the conductive contacts 12. The exposed area of the conductive contacts is slightly smaller than

the entire available area of the upper surface of the conductive contacts 12 themselves.

Step J: The remaining photoresist is removed. The passivation material slightly overlaps the conductive contacts 12 (in regions 22) for ensuring that there are no gaps between the passivation material and the contacts 12. Thus, the exposed area of each conductive contact 12 is smaller than the area of the contact 12 at the interface between the contact and the semiconductor substrate 1. In the embodiment shown the passivation material extends up and onto the contacts.

In the described method photoresist may additionally be applied to the sides and/or the lower face of the detector to protect them during the process steps. This additional photoresist on the sides can then be removed at a later step. For example, the additional photoresist can be applied at step B and can be removed at step J.

With the foregoing methods, the end result is a detector with a lower face having a uniform conductive layer (e.g. a metallised layer such as a gold layer) and an upper face having conductive contacts in a desired pattern. The method avoids the introduction of impurities from the passivation material and/or passivation etchant (e.g. aluminium nitride etchant) between the semiconductor substrate and the conductive contacts and into the conductive layer. The method ensures that at no step is there any need for an etchant for the conductive layer (e.g. a gold etchant). In addition, the passivation etchant does not come into contact with the substrate surface in the area between the conductive contacts or the edges and sides of the detector. As a consequence, during the above procedure the surface of the substrate between the conductive contacts remains unharmed, retaining very high resistivity of the order of GΩ/square, tens, hundreds or even thousands of GΩ/square and very low surface leakage current.

As high as possible resistivity between conductive contacts is desired in order to allow long integration standby or readout times of the signal created from impinging X-rays or gamma-rays, for example, without deterioration of the image resolution.

The passivation material (e.g. aluminium nitride) covers the area between the conductive contacts protecting the corresponding regions form oxidation (providing stability over time) and enhancing the inter-contact resistivity. By overlapping the conductive contacts, the passivation material ensures there are no gaps exposing the semiconductor substrate surface and increases the mechanical stability of the detector.

With the above described methods, contact pads up to about 100μm across with up to about 500μm pitch in between can be readily obtained, while retaining very high inter pixel resistivity.

Non-limiting examples of particular embodiments in accordance with the invention are given in the following.

EXAMPLE 1

Cadmium zinc telluride or cadmium telluride is used as the semiconductor substrate 1 and a platinum or indium metallisation layer is used as the conductive material 2 on the lower face of the detector in step A. The conductive material 8 in step D is formed by evaporation or electroless deposition of platinum and PVD sputtering of gold to form a stack or sequence of platinum and gold with the platinum formed on the substrate surface and the gold formed on the platinum. The passivation material 14 in step F is sputtered aluminium nitride formed by phase vapour deposition. In step I an alkali solution is used to etch the aluminium nitride.

The end result (shown in Figure 1J) is a cadmium zinc telluride/cadmium telluride substrate 30, a platinum or indium layer 32, an aluminium nitride passivation layer 34, and conductive contacts formed as a stack of platinum 36 and gold 38.

EXAMPLE 2

Cadmium zinc telluride or cadmium telluride is used as the semiconductor substrate 1, and an indium metallisation layer is used as the conductive material 2 on the lower face of the detector in step A. The conductive material 8 in step D is formed by a stack of platinum, gold, nickel and gold. The passivation material 14 in step F is sputtered aluminium nitride formed by phase vapour deposition. In step I alkali solution is used to etch the aluminium nitride.

The end result is shown in Figure 2A. Referring to this figure, the detector comprises a cadmium zinc telluride/cadmium zinc substrate, an aluminium nitride passivation layer and conductive contacts formed as a stack of platinum, gold, nickel and gold.

EXAMPLE 3

This example corresponds to Example 2 except the conductive contacts are formed as a stack of platinum 45, gold 46, indium 47 and gold 48.

EXAMPLE 4

Cadmium zinc telluride or cadmium telluride is used as the semiconductor substrate 1, and a platinum metallisation layer is used as the conductive material 2 on the lower face of the detector in step A. The conductive material 8 in step D is formed by a stack of nickel and gold. The passivation material 14 in step F is sputtered aluminium nitride formed by phase vapour deposition. In step I alkali solution is used to etch the aluminium nitride.

The end result is shown in Figure 2B. Referring to this figure, the detector comprises a cadmium zinc telluride/cadmium zinc substrate 50, a platinum layer 52, an aluminium nitride passivation layer 54 and conductive contacts formed as a stack of nickel 55 and gold 56.

EXAMPLE 5

Cadmium zinc telluride or cadmium telluride is used as the semiconductor substrate, gold is used as the conductive material and aluminium nitride as the passivation material.

In other examples, stacks of platinum/gold/nickel; platinum/gold; indium/gold; chrome/copper/gold and platinum/titanium-tungsten alloy/gold are used.

Variations of the above procedure may be applied without departing from the scope of the invention.

Figures 3, 4 and 5 are used to illustrate possible contact patterns on the upper surface of the detector substrate. In Figure 3, an array of square contact pads is shown. In Figure 4 an array of circular contact pads is shown. The use of circular rather than square contact pads increases the surface resistance between pads by increasing the amount of resistive material between adjacent pads. Figure 5 illustrates an array of offset (honeycombed) pixel pads. Once again this further increases the resistance between pads by increasing the surface amount of resistive material between adjacent pads.

It will be appreciated that rather than providing an array of contacts for defining an array of detector cells, other contact configurations, for example contact strips for defining strip-shaped detector cells, can be obtained with the same method.

It should be noted that the longitudinal dimension (width) of the top of the conductive contacts is smaller than that at the contact-substrate interface. This arises from the relative sizes of the openings to the contacts and of the contacts themselves to ensure that, when portions of the passivation material above the contacts are etched away, the etchant will not seep through to the interface between the passivation layer and the conductive contacts.

Figure 6 is a schematic cross section of part of a radiation imaging device 60. Such radiation imaging devices are known and radiation detectors constructed in accordance with the embodiments of the present invention can be used within such a device. The radiation imaging device 60 comprises a radiation detector 62 and a readout chip 64 for reading charge from the conductive contacts 12 of the radiation detector 62. The radiation detector 62 comprises conductive contacts 12 on one surface (the upper surface in Figure 6) of a semiconductor substrate 1 and a layer of conductive material 2 on another surface (the lower surface in Figure 6) of the semiconductor substrate 1. The readout chip 64 comprises circuitry for reading charge from the contacts 12 in the form of respective readout circuits 66. Readout circuits 66 are joined to respective contacts 12 via bonds 68 and may be 'flip-chip' joined (e.g., by bump bonding using low temperature soldering with tin lead bismuth (PbSnBi) alloy solder or using balls of indium or conductive polymer material, gluing using conductive materials, or other conductive adhesive layer techniques) to respective circuits.

The continuous conductive layer or electrode 2 and the conductive contacts 12 of the radiation imaging device 60 define detector calls 70. Corresponding readout circuits 66 for each detector cell are defined at locations corresponding to the detector cells 70. The readout circuits 66 are electrically connected to the corresponding contacts 12 by bonds 68 which form a conductive pathway. In this manner when charge is generated in a detector cell 70 in response to incident radiation, this charge is passed via the bond 68 to the corresponding readout circuit 66.

The readout chip may be any suitable readout chip. For example, the readout chip may be of the pulse counting type (e.g. photon counting) or one of the type which provides for charge accumulation for individual detector cells, such as that described in PCT/EP95/02056. In particular embodiments the readout chip may comprise one or more of: charge accumulation circuitry; counter circuitry; readout circuitry; energy discriminator circuitry; pulse shaping circuitry; pulse amplifying circuitry; analogue to digital converter circuitry; or rate divider circuitry.

Thus, the invention teaches how to obtain a radiation detector (e.g. based on a CdZnTe substrate) with one side metallised according to a desired pattern with maximum possible electrical resistivity separation between the metal contacts. High resistivity between metal contacts is desirable to improve contrast resolution and eliminate signal leakage between adjacent metal contacts on the substrate surface. This is particularly relevant when long charge accumulation times and long standby/readout times are employed by the readout chip. Such accumulation and standby/readout times could, for example, be in excess of 1msec in examples of imaging devices using a radiation detector manufactured in accordance with the present invention. Such imaging devices find application, for example, for X-ray, gamma-ray and beta-ray imaging as described in the applicant's International Patent Application PCT/EP 95/02056 incorporated herein by reference.

In one aspect the invention provides a method of manufacturing a radiation detector having conductive contacts on a semiconductor substrate at positions for defining radiation detector cells, said method comprising:

(a) one or more steps for forming an array of conductive contacts on a surface of said semiconductor substrate to leave regions open to the surface of said semiconductor substrate between conductive contacts;

(b) one or more steps for forming a layer of material on said conductive contacts and the regions between conductive contacts; and

(c) one or more steps for removing portions of said layer of material overlying said conductive contacts to expose the conductive contacts.

Although particular embodiments of the invention have been described by way of example, it will be appreciated that additions, modifications and alternatives thereto may be envisaged.

The scope of the present disclosure includes any novel feature or combination of features disclosed therein either explicitly or implicitly or any generalisation thereof irrespective of whether or not it relates to the claimed invention or mitigates any or all of the problems addressed by the present invention. The applicant hereby gives notice

that new claims may be formulated to such features during the prosecution of this application or of any such further application derived therefrom. In particular, with reference to the appended claims, features from dependent claims may be combined with those of the independent claims and features from respective independent claims may be combined in any appropriate manner and not merely in the specific combinations enumerated in the claims.

CLAIMS

1. A method of manufacturing a radiation detector having one or more conductive contacts on a semiconductor substrate at positions for defining one or more radiation detector cells, said method comprising the steps of:

(a) forming said conductive contacts on a surface of said semiconductor substrate to leave regions open to the surface of said semiconductor substrate around said conductive contacts;

(b) forming a layer of material on said conductive contacts and the regions around conductive contacts; and

(c) removing portions of said layer of material overlying said conductive contacts to expose the conductive contacts.

2. A method according to Claim 1, wherein step (a) comprises:

a(i) forming a layer of photoresistive material on said substrate surface;

a(ii) selectively exposing said photoresistive material and removing said photoresistive material from areas corresponding to said contact positions to expose said semiconductor substrate surface;

a(iii) forming a layer of conductive material on remaining photoresistive material and on said exposed semiconductor substrate surface; and

a(iv) removing conductive material overlying said remaining photoresistive material by removing said remaining photoresistive material.

3. A method according to Claim 1 or Claim 2, wherein step (c) comprises:

c(i) forming a further layer of photoresistive material over said layer of material;

c(ii) selectively exposing said further layer of photoresistive material and removing said further photoresistive material to expose portions of said layer of material corresponding to said contact positions;

c(iii) removing said exposed portions of material; and

c(iv) removing remaining further photoresistive material.

4. A method according to any preceding Claim, wherein said layer of material comprises a layer of passivation material.

5. A method according to Claim 4, wherein said passivation material is aluminium nitride.

6. A method according to any preceding Claim, wherein said portions of said layer of material are removed from areas smaller than said conductive contacts.

7. A method according to Claim 6, wherein after removal of said portions of said layer of material, said material overlaps said conductive contacts.

8. A method according to any preceding Claim, wherein the substrate is formed of cadmium zinc telluride or cadmium telluride and preferably wherein the conductive contacts comprise gold.

9. A method according to any preceding Claim, wherein said conductive material layer for forming said contacts is applied by sputtering, evaporation, electrolytic deposition, or electroless deposition.

10. A method according to any preceding Claim, wherein said conductive material is a metal or metal alloy or a stack of metals and/or metal alloys.

11. A method according to Claim 10, wherein said metal or metal alloy for forming said contacts comprises nickel, gold, platinum, indium, titanium, tungsten, a nickel/gold alloy or a titanium/tungsten alloy.

12. A method according to any preceding Claim, wherein each conductive contact defines a respective pixel cell of an array of pixel cells.

13. A method according to any preceding Claim, wherein each conductive contact defines one of a plurality of strips arranged parallel to each other.

14. A method according to Claim 13, wherein said conductive contacts are from about $5\mu m$ to about $100\mu m$ across with a pitch from about $7\mu m$ to about $500\mu m$.

15. A method according to any preceding Claim, wherein said conductive contacts are of the order of $15\mu m$ across with a pitch of the order of $35\mu m$.

16. A method according to any preceding Claim, wherein said conductive contacts for respective radiation detector cells are formed on a first surface of said semiconductor substrate, and a layer of conductive material is formed on a surface of said substrate opposite to said first surface.

17. A method according to Claim 16, including, prior to step (a), a step of forming said layer of conductive material on said second surface of said substrate.

18. A method of manufacturing a radiation imaging device comprising:

manufacturing a radiation detector in accordance with Claim 16 or Claim 17; and

individually connecting individual detector cell contacts for respective detector cells to corresponding circuits on a readout chip.

19. A method according to claim 18 wherein said connecting is by way of a flip-chip technique.

20. A radiation detector comprising a semiconductor substrate with one or more conductive contacts for respective radiation detector cells on a first surface thereof and a layer of conductive material on a surface of said substrate opposite to said first surface, said radiation detector being manufactured by a method in accordance with Claim 16, 17 or 18.

21. A radiation detector according to Claim 20, comprising passivation material around individual contacts.

22. A radiation detector according to Claim 21, wherein said passivation material is aluminium nitride.

23. A radiation detector according to any of Claims 20 to 22, wherein said conductive contacts define an array of pixel cells.

24. A radiation detector according to Claim 23, wherein said contacts are substantially circular and are arranged in a plurality of rows, with alternate rows preferably being offset from adjacent rows.

25. A radiation detector according to any of Claims 20 to 24, wherein said conductive contacts define a plurality of strips arranged parallel to each other.

26. A radiation detector according to any of Claims 20 to 25, wherein said metal contacts are from about 5μm about to about 100μm across with a pitch from about 7μm to about 500 μm.

27. A radiation detector according to any of Claims 20 to 26, wherein said metal contacts are of the order of 15 μm across with a pitch of the order of 35 μm.

28. A radiation detector according to any of Claims 20 to 27, wherein said semiconductor substrate is cadmium zinc telluride or cadmium telluride and preferably wherein the conductive contacts comprise gold.

29. A radiation detector according to any of Claims 20 to 28, wherein the resistivity between conductive contacts is in excess of 1GΩ/square, preferably in excess of 10Ω/square, more preferably in excess of 100GΩ/square and even more preferably in excess of 1000GΩ/square (1TΩ/square).

30. A radiation imaging device comprising a radiation detector in accordance with any of claims 20 to 29, and a readout chip for receiving charge from the conductive contacts of the radiation detector.

31. A radiation imaging device according to claim 30, said readout chip comprises one or more of the following:

charge accumulation circuitry; counter circuitry; readout circuitry; energy discriminator circuitry; pulse shaping circuitry; pulse amplifying circuitry; analogue to digital converter circuitry; and rate divider circuitry.

32. A radiation imaging device according to claim 30 or 31 wherein the individual contacts are connected to respective circuits by a flip-chip technique.

33. A method of manufacturing a radiation imaging device comprising:

manufacturing a radiation detector in accordance with Claim 16 or Claim 17; and

individually connecting individual detector cell contacts for respective detector cells to corresponding circuitry on a readout chip.

34. A method according to claim 33 wherein the readout chip comprises one or more of the following:

charge accumulation circuitry; counter circuitry; readout circuitry; energy discriminator circuitry; pulse shaping circuitry; pulse amplifying circuitry; analogue to digital converter circuitry; and rate divider circuitry.

35. A method according to claim 33 or 34, wherein said connecting is by way of a flip-chip technique.

36. A radiation detector comprising a semiconductor substrate with one or more conductive contacts for respective radiation detector cells on a first surface thereof and a layer of conductive material on a surface of said substrate opposite to said first substrate, wherein the exposed area of said conductive contact is smaller than

the area of said contact at the interface between said contact and said semiconductor substrate.

37. The radiation detector of claim 36 further comprising passivation material around the contacts.

38. A method of manufacturing a radiation detector substantially as described herein with reference to the accompanying drawings.

39. A radiation detector substantially as described herein with reference to the accompanying drawings.

40. A radiation imaging device substantially as described herein with reference to the accompanying drawings.

ABSTRACT

FORMATION OF CONTACTS ON SEMICONDUCTOR SUBSTRATES

A method of manufacturing a radiation detector having one or more conductive contacts on a semiconductor substrate (1, 30) at positions for defining one or more radiation detector cells, includes the steps of: forming said conductive contacts on a surface of said semiconductor substrate to leave regions open to the surface of said semiconductor substrate around said conductive contacts; forming a layer of material (4, 22, 34) on said conductive contacts and on the regions around conductive contacts; and removing portions of said layer of material overlying said conductive contacts to expose the conductive contacts. The layer of material (4, 22, 34) is preferably passivation material. A method according to the invention avoids the introduction of impurities between the surface of the semiconductor substrate (1, 30) and the conductive contacts (12, 36, 38) by forming the conductive contacts before layers of other material (4, 22, 34). The product of the method and the uses thereof are also described.

Figure 1J